CENTRE FOR INTERNATIONAL HEALTH – MEDICAL ALUMNI ASSOCIATION
UNIVERSITY OF TORONTO

# Bacterial and chemical contamination of drinking water in rural Cambodia

## Project Summary and Recommendations

**10/28/2007**

David D. Phillips, Hon. BA
MD Candidate
Faculty of Medicine
University of Toronto

# Contents

# Acknowledgements

This project could not have been completed without the hospitality and warm welcome we received from people of Cambodia who invited us into their homes and allowed us to catch a glimpse of their daily struggles. Special thanks go to the Cambodian Ministry of Health and their representatives at the Operational District of Kep, the physicians and nurses at local health centres, school principals, teachers and students, religious leaders and the staff and children of the local orphanages.

We would like to extend our thanks to Mikey Sampson from Resource Development International - Cambodia who heard our ideas and offered generous access to both facilities and staff.

The funding for this project was supported by the Medical Alumni Association at the University of Toronto and they must be commended for their aggressive pursuit of international opportunities for the students in the Faculty of Medicine.

The Dr. David Zakus and Dr. Rebecca Draisey from the Centre for International Health (CIH) at the University of Toronto were instrumental in planning, networking and providing energetic undergraduate students to participate in the implementation of this project.  Thanks to Risako, Kenzo, Peter, Luke, Graham for giving their time and ideas in the field and the laboratory.

# Executive Summary

**Objective** - Worldwide, 29,000 children die each day from preventable diseases and water borne illness accounts for more than three quarters of all disease and death in the developing world. Cambodia is a country that is suffering a disproportionate number of these deaths with the highest child mortality rates in the region. After 30 years of civil war the people of Cambodia have begun rebuilding and are finally seeing improvements in the quality of life. Several organizations have begun to develop initiatives to improve water access, but the risks of pathogens and the unknown chemical properties of rural water sources have hampered coordinated efforts. The goals of the research project were to improve knowledge of the location, quality and usage patterns of drinking water sources in rural areas. This information can be used to improve community planning and water source construction. **Methods** - Bacterial and chemical contamination, GPS coordinates and photographs of 153 water sources were sampled in 16 different districts in the province of Kep, Cambodia. Bacterial contamination was measured using the EZ Gel technology to provide quantification of E. coli and coliform bacteria levels. Chemical contaminants including arsenic were analyzed at RDIC, a major laboratory in Phnom Penh. **Results** - Results revealed elevated levels of E. coli in excess of WHO standards in 78% of the water sources sampled. The findings were relatively consistent across all types of wells and reservoirs. Chemical analysis revealed several trends, including a worrying finding that 60% of the samples from Thmey Village contained levels of Arsenic that met or exceeded the WHO Arsenic guideline of 10µg/L. Rain water collection systems showed very low levels of both bacterial and chemical contamination, while ceramic filters were shown to perform very well at removing microorganisms. **Conclusions** - Chemical findings suggest that arsenic levels may be clustered in certain communities, although more surveys on chemical contamination are required in this province. Findings indicate that samples should be taken and analyzed for each community before commencing new well construction projects. Bacterial results indicate a need to educate locals on the high likelihood that their water contains pathogenic microorganisms. Community-wide education hygiene campaigns and simple, low cost technologies including rain water collection systems and ceramic water filters should be widely available to the population to reduce bacterial contamination and the risks of chemical contamination of groundwater.

# Introduction

Access to clean drinking water is a luxury that the majority of the western world has come to expect and demand.  It is considered a fundamental human right; however one sixth of the world's population lives without regular access to safe drinking water and nearly 2.4 billion people do not have access to an adequate level of sanitation (Dufour A., 2003).   Furthermore, 29,000 children die each day from preventable diseases (UNICEF, 2002) and the majority of these deaths are the result of the environmental conditions that they face including a lack of access to clean water (Satterthwaite, 1996).  Clean drinking water and access to it are thus an extremely important topic and form the core of many of the United Nations Millennium Development Goals. In the words of the United Nations past Secretary-General Kofi Annan it is "a situation made all the more tragic by our long-standing knowledge that these diseases are easily preventable" (United Nations, 2003).

## Project Goals

The research project was designed to improve knowledge of the location, quality and usage patterns of drinking water sources in rural Kep province in order to facilitate improved community education, planning and water source construction.  Several NGOs have begun to develop initiatives to improve water access, but the risks posed by pathogens and unknown chemical properties of rural water sources have hampered coordinated efforts to develop community-wide interventions.

Secondary goals included training local health leaders on the techniques for the enumeration of bacterial contamination and an understanding of how to collect water samples for chemical analysis at a laboratory.

## Background on Cambodia

Cambodia is recovering from a horrific history of genocide and civil war that destroyed most of the country's public and health care infrastructure. Considered an Asian country in the early 1970's, Cambodia was plunged into a 30 year civil war when the Khmer Rouge, led by Pol Pott, overthrew the government regime marched into Phnom Penh and began a program that systematically targeted educated Cambodians, emptied the city's and decimated infrastructure in the search for an ancient and idyllic agrarian society. In 1975 Cambodia's population numbered approximately 8 million people and in a few short years over 1 million people perished through systematic genocide or starvation until the Vietnamese invasion in 1978 that drove the Khmer Rouge into the countryside. For a short and shocking read on this tragic period in Cambodia read "First They Killed My Father: A Daughter of Cambodia Remembers" by Loung Ung.

Cambodia has seen considerable progress since the removal of the last remnants of the Khmer Rouge regime and the end to factional fighting in the late 1990's.  Much remains to be accomplished and many former Khmer Rouge members remain in government positions and apparently beyond the reach of the international courts, creating an uneasy peace and an environment that is rife with corruption.

Health indicators in Cambodia are among the worst in Asia and the child mortality rates are staggering, Cambodia's under-five mortality rate of 124 per 1,000 live births is the second highest in Asia (United Nations Children's Fund, 2004).

This is in contrast with Canada, where 0.6% of children die under 5 (WHO, 2007). In Cambodia diarrheal diseases are the second leading cause of morbidity and seriously complicate the health of those struggling with the three biggest killers in the country; tuberculosis, acute respiratory infections and malaria (World Health Organization, 2004). It is thus imperative that both health interventions and education campaigns that aim to change this reality consider the role of clean drinking water considering that Cambodian government statistics indicate that more than 70% of urban Cambodian residents, who have considerably more public infrastructure at their disposal, still lack access to safe water (Cambodia Ministry of Planning, 2004).

Projects that have been conducted under previous MAA Scholarships and under the CIH have indicated that a fundamental limitation to acting on the issue of access to clean drinking water is a lack of knowledge of the current status of water quality in the Kep region. Previous projects have recommended a thorough inventory of the location, quality and type of water sources in this region. This research project has been developed with those needs in mind and tested the bacteriological and chemical quality of 153 water sources and 5 ceramic water filters being used by the Cambodian people in the Kep region.

## Introduction to Water Quality and Community Health

The UN has declared 2005-2015 the International Decade for Action on water in their "Water for Life" campaign. Although the world's attention is often attracted by more sensational and controversial health topics such as SARS, AIDS and Avian Influenza, millions of people perish each year due to inadequate access to clean water. The majority of those dead are children, with half of the 11 million child deaths occurring each year due to malnutrition and lack of access to safe water and sanitation. Perhaps more importantly, water or lack of it, fuels the conditions that allow the spread of some of the most destructive diseases faced by humanity. In the words of Kofi Annan, United Nations Secretary-General:

*"We shall not finally defeat AIDS, tuberculosis, malaria, or any of the other infectious diseases that plague the developing world until we have also won the battle for safe drinking water, sanitation and basic health care."* (United Nations, 2005).

Access to clean drinking water is an issue for two thirds of the world's population and is a major cause of preventable morbidity and mortality. The WHO estimates that approximately 1.1 billion people lack the ability to access water sources that are even modestly clean and are forced to drink whatever they can find (WHO, 2004). Lack of access to potable water is inextricably linked to poverty and inequitable access to education water also perpetuates a socio-economic system where the poor, in many countries the dominant social class, are forced to expend considerable energy confronting illness, disease and death instead of pursuing education and improving the social and economic standing of their people., health care, sanitary infrastructure and other resources. Lack of access to clean drinking

The WHO estimates that diarrheal disease alone kills 1.8 million people world-wide each year while more than a billion suffer from the effects of water borne pathogens such as schistosomiasis and hepatitis A (WHO, 2004). A large percentage of these deaths are to children under the age of 5 years. A 2005 Cambodian Government health survey showed 20 per cent of children under 5 suffered diarrhoea in the two weeks preceding the survey, and found it most common in children between 6 months and 2 years of age (Cambodia Ministry of Planning, 2004).

In some rural areas, the percentage of the population living below the poverty line rises to 79%. Access to potable water has improved, but nearly two thirds of the rural population and one quarter of city dwellers still rely on unsafe sources. Less than one quarter of Cambodians have access to safe excreta disposal (WHO, 2006).

As water-related diseases are among the leading causes of morbidity and mortality among Cambodian children, provision of safe water is a high priority for the Royal Government of Cambodia (MEF, 2004).

## Drinking Water Quality Standards

The World Health Organization (WHO) has developed Guidelines for Drinking-Water Quality with the understanding that not every country has the same social and economic climate to enable the creation of a uniform international standard on water quality (WHO, 1993). The WHO thus supports a risk-benefit approach to their recommendations for standards that account for differences in technical, financial and institutional resources throughout the world in a way that attempts to achieve "maximum public benefit" (World Health Organization, 2004). Many international and national bodies have developed standards for the evaluation of water quality and in most cases these standards have been based on the pioneering work of the World Health Organization.

## Indicator Organisms

Although there are millions of different species of protozoa, helminths, bacteria and viruses in our environment, only a few hundred generally threaten human health. Most of those microorganisms are transferred between humans in bodily secretions and fluids that we come in contact with directly or through our environment such as in drinking water. E. coli (Escherichia coli) is one of several types of bacteria that normally inhabit the intestine of humans and animals and that is excreted in the feces of humans and animals. E. coli bacteria may give rise to infections in wounds, the urinary tract, biliary tract, and abdominal cavity (peritonitis). This organism may cause septicaemia, neonatal meningitis, infantile gastroenteritis, tourist diarrhea, and hemorrhagic diarrhea. It is used as an indicator organism to infer the presence of pathogens in food and drinking water due to its association with fecal matter and its ability to be easily grown in the lab.

The WHO recommends the use of indicator organisms to assess water quality for a number of reasons:

- In order to rule out contamination, one would be required to test for hundreds of different pathogens that could potentially be transmitted to a human host.

- Some pathogens, such as viruses, are both very difficult and expensive to isolate while others simply cannot be detected using modern techniques.
- Current scientific knowledge does not provide an adequate quantifiable level of risk presented by each of the multitude of different pathogens that can contaminate water. Each person will be affected differently.

As such the WHO has chosen Escherichia coli as the predominant indicator organism because of the fact that it fulfills the criteria required of an ideal indicator organism as stated in the WHO Water Quality Guidelines (World Health Organization, 2004, p. 22) :

- Universally present in large numbers in the faeces of humans and warm-blooded animals;
- Readily detected by simple methods;
- Do not grow in natural waters; and
- Persistence in water and removal by water treatment similar to waterborne pathogens.

## Chemical Contamination

Many chemical contaminants can be instilled in both surface and ground water through both natural and human sources. For example, arsenic is a chemical that naturally deposits in the soil at varying depths and densities within and between countries and regions as well. If the depth of the water table sits within that arsenic dense soil drinking water may contain toxic levels of arsenic. Cancer, multi-organ failure and early death are all symptoms of prolonged Arsenicosis or arsenic poisoning.

There are large gaps in the knowledge of the chemical properties of drinking water throughout Cambodia and previous research has demonstrated that "there are several parameters of health and aesthetic concern; dissolved arsenic is the most significant" (Feldman, Rosenboom, Saray, Navuth, Samnang, & Iddings, 2007). Feldman et. al. (2007) found elevated arsenic levels in highly populated areas and recommended that further investigations should be conducted on the chemical contamination of drinking water in Cambodia. They found that elevated levels of a number of chemical contaminants resulted in the rejection of the water source by the population due to aesthetic reasons, and the subsequent use of water with much higher bacterial levels.

## Limitations of Water Quality Guidelines

The guidelines developed by the WHO regarding water quality have been largely adopted in the Cambodian government's Cambodian Drinking Water Quality Standards (CDWQS). The WHO has set targets that countries should aim to achieve, with the understanding that it may be next to impossible to meet these high standards in developing countries. The WHO guidelines have been developed as a guide specifically because a hard-line approach could inevitably result in the condemnation of water sources that may be the best option for a population. Labelling a source as polluted and undrinkable due to the presence of an of indicator organism may actually drive a population to more polluted sources that have not been tested or quantified for the presence of microorganisms and chemical contaminants. Condemnation of water sources could result in significant harm to the very young, the very old, the poorest and least educated.

Therefore, the main goal in utilizing a proven method for isolating and enumerating indicator organisms is to provide a tool for communities to ensure that the population has access to the safest drinking water possible under the current conditions and with available resources.

# Methods

Water quality was examined at 153 community water sources and in 5 ceramic water filters for a broad range of bacterial and chemical indicators and were compared to drinking water standards for both the WHO and the recently adopted Cambodia Drinking Water Quality Standards (CDWQS). Provincial Health Officials, physicians, health care workers and infrastructure managers from throughout Kep were involved in both field collection and laboratory analysis. Team members from Bridges Without Borders, an NGO working on infrastructure and drinking water initiatives in Chong Kneas village, were also trained on water evaluation techniques. It is hoped that the information from this report will assist them in their strategy to install new water sources.

## Field Techniques

The field work was conducted by a team of 5 undergraduate students and led by a medical student from the University of Toronto. The samples were collected in June and July, 2007 in Kep province, a small province of Cambodia located on the Gulf of Siam (aka. Gulf of Thailand). Sources were identified by locating the 16 village centres throughout the province and performing a grid exploration of available roads and paths leading out of those centres. Water sources were also identified by speaking with local residents in an informal way to ascertain the locations of commonly used water sources. In rural Cambodia many wells have been constructed by NGOs and governmental organizations and placed in prominent locations to be easily accessed by all. Two teams worked in concert with a translator to identify well locations that were being used by the local population and also to establish how they collected, treated and utilized the water. Each source was marked with a GPS coordinate, photos were taken and water temperature was recorded. Two separate samples were taken in the field, a 500mL sample to be used for chemical analysis and a 50mL sample was collected in a sterilized bottle for bacterial evaluation. The bacterial sample was promptly stored on ice until the team returned from the field to plate the samples on the Easy Gel medium and transfer 100mL of the 500mL sample to an acid infused bottle supplied by the chemical laboratory analyzing the chemical contaminants in the water.

## The Easy Gel Technology

The Coliscan Easygel medium is a patented formulation for water testing which has been approved for use by the United States Environmental Protection Agency (EPA) for the monitoring of bacteriological content in surface waters. It is a very simple and inexpensive technology that has produced reliable results in several studies (Grant, 1997). Coliscan Easygel medium contains a sugar linked to a dye which, when acted on by the enzyme β-galactosidase (produced by coliforms including E. coli), turns the colony a pink color. Similarly, there is a second sugar linked to a different dye which produces a blue- green color when acted on by the enzyme β -glucuronidase. Because E. coli produces both β -galactosidase and β-glucuronidase, E. coli colonies grow with a purple color (pink + blue). The combination of these two dyes makes possible the unique ability to use one test to differentiate and quantify coliforms and E. coli.

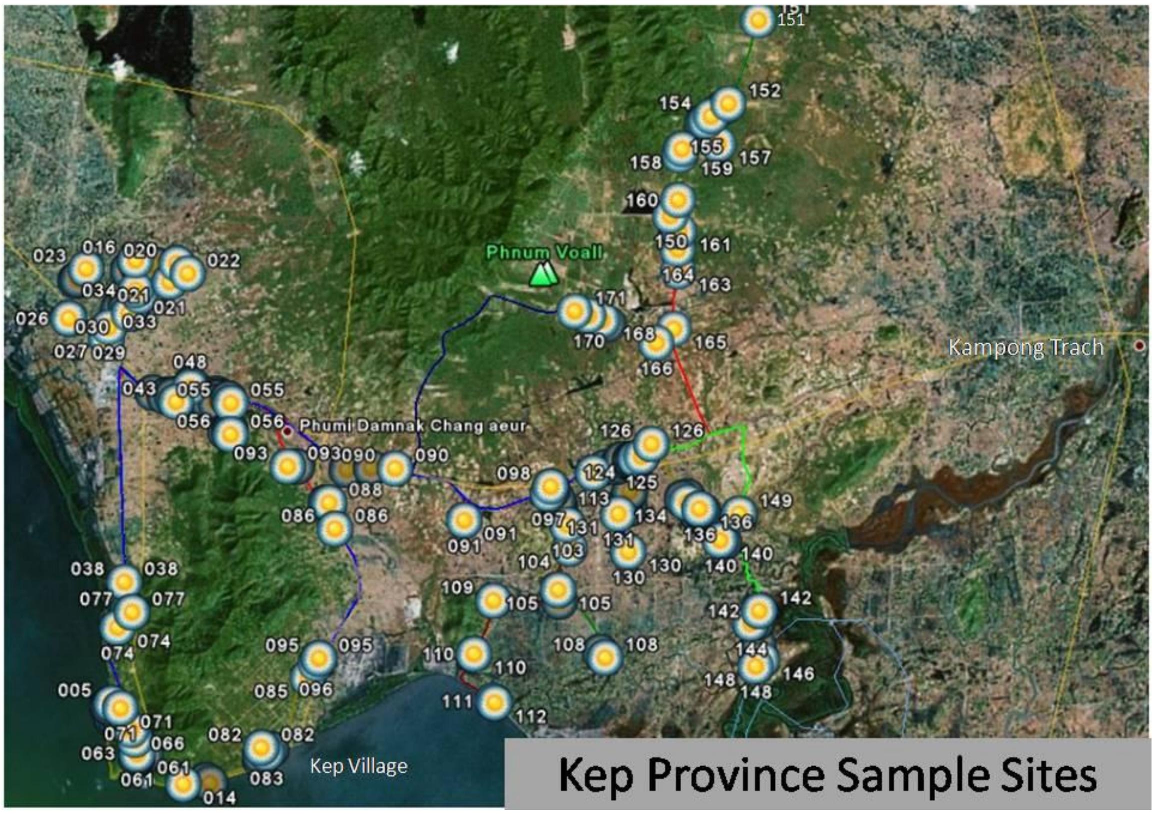
## Laboratory Practices

Separate samples to evaluate chemical contaminants were taken at the source in 500mL bottles and an acid infused 100mL bottle which were transported weekly to Resource Development Initiatives –Cambodia (RDIC), a partner NGO with extensive water testing facilities.

Sanitized Collection bottles were used to collect bacteria samples and they were stored on ice until they were returned to the field station for processing, which occurred within 6 hours of sampling.  In the laboratory 3 small samples of water (5 mL) were inoculated into 3 separate sterile EZ Gel agar jars.  The EZ Gel inoculum is then poured into a special treated Petri dish that causes the inoculated medium to harden within one hour.  The Petri dishes were stored between 28 and 32 degrees Celsius for 24 to 36 hours in a portable incubation chamber loaned to the CIH by RDIC.  Results are obtained after 24-36 hours and provide quantification of indicator organisms. After results are obtained the inoculated dishes are destroyed as biohazard material along with other health care waste produced at health care facilities.  See APPENDIX 3 for instructions on interpreting results.

# Results

The project team sampled 153 water sources in 16 villages within the 5 communes of Kep province. The map pictured in Figure 1 demonstrates the geographical area and the distribution of samples recorded on a Garmin GPS Unit.




## Province Wide Trends

- 69.73% of the water sources sampled were used as the primary water source for drinking water in the 16 villages sampled. Of the other 30.27% of sources sampled that were not used for drinking purposes, most people reported that they did not drink the water because it was un-palatable.
- 75.81% of the sources sampled throughout Kep Province contained detectable levels of E. coli. The ideal level would be 0 E. coli per 100mL in order to meet the WHO designation as safe.
- Of the 106 sources that people used as their primary source, 75% (n= 79) reported that they drank the water without any intervention or technique for disinfection such as boiling or ceramic water filters.
- 23.5% of all samples met or exceeded the WHO criteria of 10 µg/L for arsenic, while 3 of 153 exceeded the recently adopted CDWQS for arsenic of 50 µg/L.
- Rain fed water systems performed extremely well with the lowest bacterial levels and undetectable arsenic levels.

## Water Source Type Trends

### Non-Primeable Pump

Non primeable pumps require only that the user move the pump handle up and down to begin a flow of water into a personal container. 28.6% of the 22 non-primeable pumps tested contained a detectable level of E. coli. The average level of contamination for non-primeable pumps was 14.603 E. coli per 100mL. 42.85% of the non-primeable pumps were not used for drinking water, with taste being the major reason for not using the pump. This type of water was often referred to as "Oxen Water" by the locals. Arsenic levels in non-primeable pumps revealed that 22.7% (5 of 22) met or exceeded the WHO standards, while only 1 exceeded the CDWQS.


### Primeable Pumps

Primeable wells require that the user first inject a small quantity of water into the housing in order to create the suction necessary to draw the water into the pump and to push out the outlet nozzle. This requirement does present an opportunity for inoculation of bacteria into the system by the user if either the priming water, the bucket or both contain bacteria. 71.4% of the 21 primeable wells tested were found to be contaminated with E. coli. The average bacterial load for primeable wells was 175 E. coli per 100mL. Arsenic testing for the 21 primeable pumps revealed that none exceeded the CDWQS standards while 4 of 21 (19%) exceeded the WHO standards.

### Open Pit Wells

Open pit wells are constructed by digging a hole into the ground until ground water is reached. In most cases the hole is then secured from collapse by inserting a concrete tube which is left open to the air. The water is then collected by a bucket, usually a communal bucket, left on the ground near the well. All of these features predispose this type of well to considerable contamination on top of any contamination that may be found in the persons own bucket or storage system at home.


A total of 84 open pit wells were sampled and bacterial results demonstrated that 94% of them were contaminated with E. coli. This result is both startling and at the same time not unexpected, as

the above paragraph mentions the variety of methods that bacteria and fomites can be introduced to the water source. The average bacterial load was determined to be 377 E. coli per 100mL. Arsenic testing for the 84 open pit wells revealed that 5 exceeded the CDWQS standards while 20 (24%) met or exceeded the WHO standards.

### Rain Water Collection Systems

There are a large variety of techniques that can be used to capture rain water during periods of high rainfall to be stored for use during the dry season. The usual collection method involves diverting the gutters on the roof of the house into a concrete silo or cylinder that is protected from airborne particulate, animals and insects and that delivers water on demand through a gravity fed nozzle. Our general impression was that families highly valued this resource and took some pride in the rain fed systems. 10 rain fed systems were tested and the general sentiment from the people who used these systems was that the taste of the water was far superior to the other options they had available. 20% of the rain fed systems had detectable levels of E. coli. The average bacterial load from the rain systems was 2 per 100mL, the lowest levels of all the types of systems tested. Arsenic levels were not detectable in any of the rain fed water sources. To the right is a rain water collection cylinder fed from a roof gutter. Note the spherical design with a secure lid which prevents entry of insects and their larvae, as well as animals and curious human hands.

### Reservoirs

Reservoirs are open pits that have been hand dug or machine dug by either the community themselves or an NGO or governmental organization that collect water during the wet season and serve as a communal water collection area.

These types of water sources appear to hold considerable significance for the local people who use them. It was often found that people who had an open pit or pump well very close to their residence would travel some distance to collect their water from a reservoir.

The reasons for making this extra effort were often related to taste, local folklore and the opinion of local elders that these tasted better and had lower levels of contamination that the "Western" pumps that had been installed. 16 reservoirs were sampled and 81.25% were contaminated with E. coli. The average

plate count was found to be 489.6 E. coli per 100mL. Arsenic levels for reservoirs were found to exceed the WHO arsenic levels in 43.75% while 6.25% exceeded the CDWQS.

## Ceramic Water Filters

Although field testing ceramic filters was not a research goal, opportunities to take samples were performed if they were found at a site. Field samples confirmed the effectiveness of ceramic filters at significantly reducing bacterial loads in drinking water.

Ceramic filters are an extremely simple and inexpensive solution to reducing the burden of illness of their users. A CIDA study conducted in northern Cambodia found significant differences among the users of ceramic filters and their local villagers over a long period. There are several types currently being in produced by Cambodia. They all share a similar structure of a small plastic garbage fitted with a ceramic clay pot placed inside. The lid is removed and the water is placed inside the ceramic pot, which filters the water in the porous clay and collects in the bottom of the plastic bin. The user can have on access water throughout the day with the equipped faucet.


The filter has a cost of $9 US in Cambodia from both the Red Cross and RDIC in Phnom Penh. Several organizations have begun to distribute the filters with various marketing and donation techniques such as the Rabbit Filters, although efforts have been fragmented. Field samples were taken on only 5 ceramic filters, but in this small sample their performance was excellent with 0 of 5 yielding E. coli. The families who owned them all agreed they valued it as a resource and stated that they always drank directly from the source and liked that they could select virtually any water source depending on the environmental conditions and season.

## Thmey Village

Thmey is a roadside village found within Preythom Commune. 80% of the samples in this community contained detectable levels of arsenic and 60% of the 20 sources sampled showed arsenic levels at or above the WHO guideline of 10µg/L. 70% of the samples from this village also contained detectable levels of E. coli, which is slightly below the average of 78% for all samples.

## Chong Kabey

Bridges Without Borders is currently working in Chong Kabey village in partnership with the local health officials and they have plans to begin a water source construction project in the near future and were interested in the results from our survey in this area. Results for bacterial evaluation indicate that 86.4% of the sources in this village are contaminated with E. coli while 4.5% (n=1) of the 22 wells exceeded the CDWQS of 50µg/L and 13.6% met or exceeded the WHO standard of 10µg/L.

# Recommendations

There is no way of effectively predicting which type of water source will be free of bacteria and chemical contamination without conducting samples on each source of interest. It is thus not possible to predict which water source will be safe to drink without treatment of the water to remove pathogens, and considerable variation is likely to occur depending on the season. Chemical results provide an interesting insight into the unique advantages of the rain water collection systems, as these systems contained no arsenic contamination and also had the lowest bacterial loads of all samples tested.

It is important to note however that people have varying degrees of understanding on how to prevent water borne illness and rumour and myth appear to play an important role in the water sources that people select and the methods that they use to treat their drinking water.

As previously mentioned, the WHO and other bodies have developed guidelines with the understanding that it may be next to impossible to expect these high standards in developing countries. These standards have been developed as guidelines specifically because a hard-line approach could inevitably result in the condemnation of water sources that may the best option for a population. Labelling a source as polluted and undrinkable because of the detection of indicator organisms or chemical contaminants may actually drive a population to more polluted sources that have not been tested or quantified for the presence of E. coli and chemical contaminants. This could result in significant harm to the poorest and least educated. The main goal of water testing should be to provide a tool for community leaders to educate the population and to ensure that people are consuming and the safest drinking water *possible* under the current conditions and with available resources for treatment and storage.

This information should be shared with all local community level leaders. The Ministry of Health and some Commune Chiefs have been made aware of the findings, but in this climate the local village chiefs are in the best position to influence the knowledge and activities of the villagers.

Thmey village should be considered as a high priority for an alternative water source intervention such as rain water collection systems as it appears that the groundwater contains high levels of arsenic. More studies should be performed to confirm the presence of arsenic in the groundwater in this village and great care should be taken when sharing this information with local residents and leaders, as great concern could be generated and more risky behaviours may result in an effort to drink from “uncontaminated” sources that have not been evaluated.

The Ministry of Health should consider a province wide education campaign on the impacts of untreated water on human health and provide education and materials to facilitate healthier practices, particularly in the area of sanitation and safe ways to dispose of human waste. More emphasis should be placed on the value of rain water collection systems and the use of ceramic water filters, which have been tested extensively in Cambodia and have been shown to reduce the burden of disease in rural populations (Roberts, 2003 ).

Ceramic Water Filters are used as way of purifying any type of water source and are a point of use technology that is relatively inexpensive and extremely effective at reducing bacterial levels. Previous studies of their effectiveness have been performed in Cambodia and throughout the world that have verified their efficacy (International Development Enterprises, 2003).

Those who cannot afford to purchase a filter should be strongly encouraged to always boil the water they use for drinking and food preparation.  A rain water collection and ceramic water filter distribution campaign is a low cost and sustainable way to improve water quality in Kep Province.

# Future research

Numerous projects can be implemented in the near future in relation to the findings in this research project:

- Distribution of the results of this survey to local stakeholders including the appropriate educational messages.
- What is the knowledge and training of health care workers in relation to water borne illness and what barriers are there to effectively giving key water safety and hygiene messages?
- What are the barriers to implementing ceramic water filter and rain water collection projects in Cambodia? A student could look at forming partnerships between NGOs to increase the distribution and use of these highly effective filters and water collection systems.
- What best practices in hygiene and drinking water treatment can be applied to Cambodia? A comprehensive education campaign on how to secure safe drinking water is required, and should involve health care workers, teachers and religious leaders and be performed in way that is appropriate to the cultural and economic setting.

# Bibliography


A. K. Umble, L. E. (n.d.). Water Environment & Technology . 57-59.

Cambodia Ministry of Planning. (2004). *Cambodia Inter-Censal Population Survey 2004, General Report.* Phnom Penh: NIS (National Institute of Statistics of Cambodia).

Dufour A., S. M. (2003). *Assessing microbial safety of rinking water: Improving approaches and methods.* World Health Organization.

Feldman, P. R., Rosenboom, J.-W., Saray, M., Navuth, P., Samnang, C., & Iddings, S. (2007). Assessment of the chemical quality of drinking water in Cambodia. *Journal of Water and Health* .

Grant, M. (1997). A new membrane filtration medium for simultaneous detection and enumeration of Escherichia coli and total coliforms. *Appl. Environ. Microbiol.* , 63:3526-30,.

International Development Enterprises. (2003). *CERAMIC WATER PURIFIER CAMBODIA FIELD TESTS.*

MEF. (2004). *2004 Medium-Term Expenditure Framework for Cambodia: 2005-2007.* . Phnom Penh: Ministry of Economy and Finance.

Roberts, M. (2003 ). *CERAMIC WATER PURIFIER CAMBODIA FIELD TESTS IDE Working Paper No. 1.* Phnom Pehn: International Development Enterprises .

Satterthwaite, D. e. (1996). *The Environment for Children.* New York: United Nations Children's Fund and Earthscan Publication.

UNICEF. (2002). *The State of World's Children 2002, table 1.* New York: United Nations Children's Fund .

United Nations Children's Fund. (2004). *2004 Official Summary of the State of the World's Children.* New York: UNICEF .

United Nations. (2005). *Actions taken in organizing the activities of the International Decade for Action, "Water for life",2005-2015: Report of the Secretary-General; ; .* New York: United Nations.

United Nations, 2003. (2003). *UN Press Release*. Retrieved from United Nations, 2003: http://www.un.org/news/Press/docs/2003/sgsm8707.doc.htm

WHO. (2006). *Cambodia Country Profile.* Geneva: World Health Organization.

WHO. (1993). *Guidelines for Drinking Water Quality. Volume 1: Recommendations.* Geneva: World Health Organization.

WHO. (2004). *Water, Sanitation and Hygiene Links to Health - Facts and Figures 2004.* Geneva: WHO Press.

WHO. (2007). *World Health Statistics 2007.* Geneva: WHO Press.

World Health Organization. (2004). *Country Situation and Trends (Cambodia).* Manila: WHO Press.

World Health Organization. (2004). *Water Quality: Guidelines, Standards and Health, 3rd Edition.* Geneva: World Health Organization.